Long-term Population Monitoring of Northern Idaho Ground Squirrel: 2021 Implementation and Population Estimates

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EXECUTIVE SUMMARY

We implemented the eighth full year of the northern Idaho ground squirrel (*Urocitellus brunneus*; NIDGS) long-term population monitoring strategy in 2021. The sampling frame consisted of the original 1,757 100 m x 100 m grid cells across occupied habitat, plus an additional 1,173 grid cells from an expanding stratum of cells. We conducted line-transect distance surveys in 1,233 cells and recorded 1,650 NIDGS at 569 cells (46%). From these data program DISTANCE estimated a density of 0.67 squirrels/ha and a total population size of 1,963 squirrels (95% CI: 1,736–2,196). We post-stratified data based on relative density (higher, lower, or unknown), with resulting densities of 0.70 squirrels/ha in stratum 1, 0.51 squirrels/ha in stratum 2, and 0.71 squirrels/ha in stratum 3. Corresponding unadjusted population sizes were 951, 201, and 829, respectively. Our adjusted index to overall abundance was 2,748 NIDGS. We compared the 1-year change in population estimates between 2021 and 2020 in 3 ways: from the DISTANCE analyses of survey data from all 3 strata, from DISTANCE analysis of 500 core grid cells intended to be surveyed every year, and from a pair-wise comparison of the 500 core cells. Overall, our indices reflected a drop in the NIDGS population in 2021. Based on analyses of all data, 20% fewer NIDGS groups were detected in 2021 compared with 2020. Similarly, the overall population estimate was lower and the pair-wise comparison of core cells showed a significant drop in 2021. From additional surveys not represented by line-transect surveys, we detected 98 NIDGS across 889 ha. To model NIDGS occupancy across the range, we used 6 environmental variables and 4 variables characterizing NIDGS occurrence as site covariates with program PRESENCE. The combination of tree canopy cover, soil bulk density, and the average number of NIDGS detections immediately adjacent to a grid cell (3x3 cell neighborhood), with constant probability of detection across visits, was the best predictor of a cell being occupied. We applied this model to the full 2,930-cell sampling frame to generate estimates of occupancy across the current NIDGS range. Roughly a third of the cells in our expanded sampling frame had >75% probability of being occupied; 15% had a very low (<10%) probability of being occupied. In summary, NIDGS abundance was lower in 2021 compared with 2020 and we detected them in fewer places. Periodic expansion of the sampling frame to encompass changing NIDGS distribution on the landscape has proved to be an important part of the monitoring design.

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INTRODUCTION

The northern Idaho ground squirrel (*Urocitellus brunneus*; hereafter NIDGS) is a rare, endemic mammal whose currently known distribution is limited to a 29 km x 37 km area in Adams County and a single disjunct population within a 3 km x 4 km area of Valley County in west-central Idaho. Within this range NIDGS occur at ~60 locations at 1,050–2,300 m elevation. Occupied sites are quite variable in size (1 to >100 ha) and density of squirrels (Wagner and Evans Mack 2012). Typical habitat includes dry montane meadows or open scablands surrounded by ponderosa pine (*Pinus ponderosa*) or Douglas-fir (*Pseudotsuga menziesii*) forest (Yensen 1991).

Decline of NIDGS through the 1980s and 1990s was attributed primarily to changes in habitat that subsequently isolated populations. Fire suppression allowed forests to encroach into meadows, reducing the amount of habitat available to squirrels and closing off dispersal corridors (Sherman and Runge 2002). It also was hypothesized that fire suppression and land conversions resulted in poorer quality food plants that lacked the nutritional value squirrels needed to sustain prolonged hibernation (Sherman and Runge 2002, Yensen et al. 2018). More recently, fleas carrying sylvatic plague have been recognized as a possible threat to NIDGS populations if low levels of enzootic plague are preventing NIDGS populations from reaching higher densities (Goldberg 2018, Goldberg et al. 2020). Goldberg (2018) found that reduced flea loads on NIDGS and other small mammals resulted in higher survival rates. Other threats to NIDGS populations identified in the Recovery Plan (USDI Fish and Wildlife Service 2003) include competition with the larger Columbian ground squirrel (*Urocitellus columbianus*), loss of habitat to development, and shooting. An emerging issue is the presence and possible expansion of invasive grasses in occupied NIDGS habitat (E. Yensen, personal communication). Natural predators include badger (*Taxidea taxus*), red fox (*Vulpes fulva*), coyote (*Canis latrans*), and diurnal raptors.

The NIDGS was federally listed as Threatened in 2000 and a recovery plan completed in 2003 (USDI Fish and Wildlife Service 2003). Recovery criteria incorporate numerical and geographic goals, including overall effective population size >5,000, a stable or increasing population trend over 5 years, and sufficient distribution across the range to maintain secure, self-sustaining metapopulations. Thus, in addition to monitoring changes in overall population size, there is a need to track population size and trend at several scales, including over the entire range, within recovery areas, and at the metapopulation level.

In 2014, we implemented a new long-term monitoring approach that combined grid-based line-transect distance sampling with patch occupancy theory (Evans Mack et al. 2013). The distance-based sampling component of the design yields estimates of density and abundance (Buckland et al. 1993), providing a statistically valid, repeatable approach for estimating population size and trend each year for a time frame of 20–30 years. The patch occupancy component tracks spatial occurrence (MacKenzie et al. 2006). Together these 2 tools allow managers and regulatory agencies to assess the status of NIDGS relative to population recovery goals. The 2014 sampling frame formed the baseline for monitoring through the life of the long-term monitoring plan.

This report summarizes the 2021 field season, which was the 8th year of implementing the current long-term monitoring design. Objectives were to:

1) conduct systematic distance sampling on transects from a sample of units selected from the grid-based sampling frame;
2) conduct presence/absence surveys at sites that were not selected for surveys under the grid-based sampling design;
3) calculate population and occupancy estimates; and
4) compare results across years.

STUDY AREA

The known NIDGS distribution extends across Adams County from northwest of Council north to Smith Mountain and east to New Meadows in the Bear Creek, Lick Creek, Lost Creek, Weiser River, and Mud Creek drainages. A disjunct population occurs in Round Valley, Valley County (Figure 1). The study area encompasses all identified NIDGS sites except for those known to be 'extinct' (e.g., Van Wyck inundated by Cascade Reservoir).

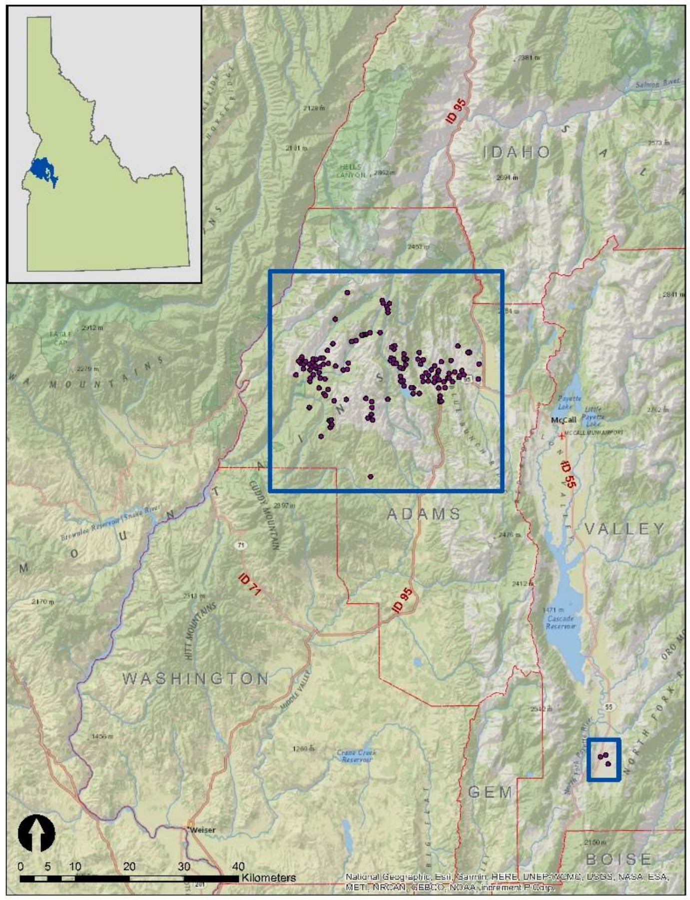

Figure 1. Known occupied range (blue squares) and locations (dots) of northern Idaho ground squirrel survey sites in 2021.

METHODS

Sampling Frame

The basis for NIDGS long-term population monitoring is a sampling frame that consists of 100 m x 100 m grid cells corresponding to known or predicted NIDGS occurrence. The sampling frame expanded to 2,930 grid cells in 2021. The original sampling frame finalized in 2014 included 1,757 grid cells that contained at least 40% of modeled NIDGS habitat (Evans Mack et al. 2013). These cells were assigned to 2 strata (stratum 1 and stratum 2) based on NIDGS densities at the time.

The sampling frame was designed to allow for expansion over time as new areas were identified to be surveyed. In 2018, we added 833 new cells (referred to as stratum 3) that included: (1) cells that did not meet the 40% overlap rule but occurred along the outer perimeters of currently occupied sites, (2) cells that encompassed previously occupied sites whose current status was unknown, (3) cells that encompassed areas where NIDGS had been discovered since 2013, (4) cells encompassing modeled suitable habitat (Crist and Nutt 2008) which had never been surveyed, and/or (5) cells encompassing areas that will be treated (thinned and burned) to create new habitat. In 2021 we expanded Stratum 3 again. Of the 2,930 grid cells currently surveyed for long-term monitoring, 66% occur on private land, 33% on land managed by the U.S. Forest Service, 6% on state land, and a small group (13 grid cells) on land managed by the Bureau of Land Management.

Annual Surveys

Each year's survey is based on a rotating panel of randomly selected grid cells that was established in 2014 for the original strata 1 and 2, and a 2021 modified stratum 3. Across the 3 strata approximately 1,310 cells are surveyed each year. This includes a core sample of 500 cells from strata 1 and 2 that are surveyed every year, and a rotating group of 810 cells that changes each year (Figure 2). All 2,930 cells are visited within 3 years. This approach is a compromise between sampling the same grid cells every year, which should give the earliest indications of trends in abundance, and wanting to ensure that all sites are represented in the long-term assessment of trends. We assigned grid cells to a panel according to their 'rank' from the spatially-balanced equal-probability sampling procedure Balanced Acceptance Sampling (BAS; Robertson et al. 2013). Strata 1 and 2 follow the original BAS ranking from 2014. We conducted a separate BAS ranking for stratum 3 when it was created in 2018 and again in 2021when it was revised.

2020 Sample	BAS rank
Stratum 1 & 2	
Panel 1 (n=500; core sample)	1-500
Panel 2 (n=419)	501-919
Panel 3 (n=419)	920-1338
Panel 4 (n=419)	1339-1757
Stratum 3 (2018-2020)	
Panel 1 (n=278)	1 - 278
Panel 2 (n=277)	279 – 555
Panel 3 (n=278)	556 - 833
2021 Sample	**BAS rank**
Stratum 1 & 2	
Panel 1 (n=500; core sample)	1-500
Panel 2 (n=419)	501-919
Panel 3 (n=419)	920-1338
Panel 4 (n=419)	1339-1757
Stratum 3 (2021-2023)	
Panel 1 (n=391)	1 - 390
Panel 2 (n=391)	391 - 781
Panel 3 (n=391)	782 - 1173
2022 Sample	**BAS rank**
Stratum 1 & 2	
Panel 1 (n=500; core sample)	1 - 500
Panel 2 (n=419)	501 - 919
Panel 3 (n=419)	920 - 1338
Panel 4 (n=419)	1339 - 1757
Stratum 3 (2021-2023)	
Panel 1 (n=391)	1 - 390
Panel 2 (n=391)	391 - 781
Panel 3 (n=391)	782 - 1173

Figure 2. Rotating panel design for determining grid cells to be surveyed in successive years (blue highlighted rows) as part of northern Idaho ground squirrel long-term population monitoring. Stratum 3 was resampled in 2021 based on the revised number of grid cells.

Line-Transect Distance-Based Surveys

Each grid cell contained 2 parallel, north–south, 100-m transect lines positioned 50 m apart and 25 m from the edge of the cell (Figure 3). To keep line-transect sampling aligned with the overarching patch occupancy framework and to increase survey independence with regard to variables such as weather conditions and time of day, we made ≥2 independent visits to each cell (MacKenzie et al.

Figure 3. Portion of 2021 sampling frame with 100-m x 100-m grid cells, cells selected for surveys, and 2 parallel 100-m long transect lines per cell.

2006). We walked 1 line on the 1st visit and the other line on the 2nd visit. In cases where a line was not walkable (e.g., private property, water, dense vegetation), the 1st line was surveyed twice.
Cells within the same geographic area generally were surveyed on the same day. We surveyed all selected cells the same way regardless of stratum.

Coordinates for start and end points of transect lines in all selected cells were uploaded from ArcMap™ v10.6 (ESRI® 2017) to hand-held Global Positioning System (GPS) units for navigation in the field. For each initial NIDGS detection (visual or aural), we recorded perpendicular distance from the line, group size, and marked the point on the line with a hand-held GPS. Prior to the first survey all crew members practiced distance estimations along a mock transect line with stakes at various distances. Each person also carried a laser rangefinder to confirm estimations and for use with longer distances.

Surveys followed existing protocols for optimizing detections (e.g., time of season, time of day, and weather; Evans Mack 2016) and site visits were scheduled to coincide with spring emergence when squirrels were particularly active and before vegetation had grown to obscure them. The majority of surveys were conducted before pup emergence to standardize all surveys for the adult/yearling portion of the population. A survey was canceled, discounted, and repeated in full at another time if interrupted by weather, predator presence, or other factors that created sub-optimal survey conditions. Columbian ground squirrels were recorded on surveys in the same way as NIDGS.

Presence/Exploratory Visits
Adding new grid cells to create stratum 3 greatly reduced the number of known sites that had no grid cells selected for surveys in this year's sample. However, for those few areas "missed" in the 2021 selection process, we conducted informal surveys to document presence. We also visited areas

where NIDGS had been detected during 2019 or 2020 exploratory surveys that were not already included in the revised stratum 3. We attempted to visit each site 1 or 2 times to establish their status. Observers walked through a site or observed from a stationary point for approximately 15–30 minutes. Squirrels detected visually and aurally were marked with GPS and the site was considered occupied. We also conducted exploratory surveys to gain a better understanding of NIDGS occurrence and dispersal corridors within the known distribution. We targeted habitat between or adjacent to known occupied locations where we thought squirrels could have expanded into. None of the individuals detected on these visits were included in analyses of population size.

Analyses

Abundance

We analyzed line-transect survey data with program DISTANCE v7.2 (Thomas et al. 2010). We defined the area of inference as 2,930 ha, corresponding to the adjusted sampling frame from which our survey sample was drawn (1,757 cells in strata 1 and 2 plus 1,173 cells in the revised stratum 3). We used a 5% truncation (i.e., the distance corresponding to the last 5% of the observations, ordered from smallest to greatest distance from the line) to reduce outlier effects on model estimates (Buckland et al. 1993). Observations were truncated at 70 m. We defined a model to estimate density using a global detection probability and encounter rate, and global density based on clustered observations. We examined half normal, hazard rate, and uniform estimators, all using the cosine series expansion. Model selection was based on Akaike's Information Criterion (AIC; Burnham and Anderson 1992). Measures of precision and confidence intervals were obtained by bootstrapping the original sample of units (Manly 1997) using the bootstrap procedure within program DISTANCE and specifying 999 replicates.

We subsequently ran a second, separate analysis of the data using stratum as a layer. We estimated encounter rate and density by stratum, detection probability and cluster size for all data combined, and a pooled estimate of density from area-weighted stratum estimates. All other model specifications were the same as described above for the entire data set.

Estimates of population size from program DISTANCE provide an index to abundance. Distance-based line-transect sampling takes into account that some animals will be missed on surveys, but it also assumes that all individuals are 'available' for detection or non-detection. Some unknown number of squirrels will be underground during NIDGS line-transect surveys and not available to be counted. We adjusted estimates of population size from program DISTANCE upward by a factor of 1.4 to obtain an approximate abundance. This adjustment factor was calculated from a comparison of abundance estimates from line-transect surveys and mark-recapture at 10 sites in 2020 (Wagner and Evans Mack 2020). The comparison showed that 1.4 squirrels were present for every squirrel detected on a survey.

Change in Abundance

We compared the 1-year change in population estimates (2020 to 2021) in several ways. First, we looked at population estimates from program DISTANCE for all 3 strata each year. For a tighter comparison we ran DISTANCE analyses on just the 500 core grid cells that are surveyed every year (ranks 1–500 from the BAS sampling procedure, strata 1 and 2 only). Lastly, we conducted a cell-to-cell analysis (paired *t*-test) with the core 464 grid cells surveyed in both years (34 of the 500 cells were not surveyed in 2021 due to limited access and a separate 2 cells were not surveyed in 2020).

NIDGS Distribution (Occupancy)

We analyzed line-transect survey data with program PRESENCE v2.13.10 (Hines 2006) to predict occupancy across our baseline grid of NIDGS habitat. The occupancy analysis was based on the same dataset (grid cells) analyzed with program DISTANCE, but also included any third visits to transect lines. Some detections made from within a grid cell were of NIDGS groups beyond the cell boundary. We removed these detections from the occupancy analysis rather than re-assign the detection to the appropriate cell. Our rationale was that the sampling design was intended to estimate occupancy based on detections within each cell following line-transect sampling, not to use any available data to claim a cell as occupied (L. McDonald, personal communication).

We incorporated 6 environmental variables as covariates in our occupancy analyses that we developed in previous years: a measure of tree canopy cover, preponderance of south-facing aspects, heat load index, bulk density of soil, soil depth to restrictive layer, and proportion of silt in the 30–100 cm soil depth layer. We also included 4 variables to characterize the occurrence of other squirrels in and around each grid cell. Covariate descriptions and data sources are summarized in Appendix A. For the soil variables, we extracted values at known squirrel locations from the past 3 years (2019–2021) within each cell and calculated the average covariate value from each sample point within a grid cell to generate a mean covariate value for each cell. For cells with no detections, we used the center point of each of the 2 survey transects in each grid cell to extract covariate values. For heat load, tree canopy cover, and southerly aspects, we averaged values within a 100-m neighborhood of squirrel locations. For the occurrence of other squirrels, we calculated the mean number of grid cells occupied and the mean number of detections within each of 2 ‘neighborhoods’ around each grid cell: 3 cells x 3 cells and 5 cells x 5 cells. We standardized most covariate values with a Z transformation (Donovan and Hines 2007).

We used the single season group of models in PRESENCE and first compared a suite of models based on the 6 environmental covariates. The reference model was a simple model assuming single probabilities of occupancy and detection across all sites. A second reference model assumed a single probability of occupancy but varying detection probability across visits. The remaining models in this set examined environmental site covariates with either a single probability of detection across visits or variable detection across visits. We repeated this process with a second set of models using the highest ranking environmental covariates from the first set combined with the 4 NIDGS occurrence variables. Model selection was based on AIC. Measures of precision and confidence intervals were obtained by bootstrapping the original sample of units (Manly 1997) using the bootstrap procedure within program PRESENCE. We applied the “best” model to all 2,930 grid cells in our expanded sampling frame, using covariate values to predict probability of occupancy for the cells we did not survey this year.

RESULTS

Distance Sampling and Analysis

Of the 1,310 cells selected for surveys in 2021 across all strata, 77 were not surveyed due to lack of access (landowner permission). The majority of surveys were completed between 14 April and 26 June 2021. The 1,233 cells analyzed represented 246.40 km of effort. We recorded 1,615 groups of NIDGS (representing 1,650 individuals) at 569 of these 1,233 cells (46%). From these data, program DISTANCE estimated a detection probability of 0.69, a density of 0.67 squirrels/ha, and a total population size of 1,963 squirrels (Table 1). Based on AIC, model 1 from the hazard rate set of models was significantly better than the next best models in the half-normal and uniform sets. We used that single hazard rate model to estimate density and population size. We detected up to 2 squirrels together, but most detections were of single animals. Average group size was 1.02 squirrels. Detection probability accounted for 16% of the variation in the density estimate, whereas encounter rate accounted for 84% and cluster size had almost no influence. In our stratified data set there were substantially more grid cells in stratum 1 (53%), fewest in stratum 2 (16%), and 31% in stratum 3 (Table 2). Correspondingly, most (55%) of the NIDGS detections occurred in stratum 1. The separate DISTANCE analysis using strata as a data layer resulted in density estimates of 0.70 squirrels/ha in stratum 1, 0.51 in stratum 2, and 0.71 in stratum 3, with unadjusted population sizes of 951, 201, and 829, respectively (Table 2).

Table 1. Modeled global population parameters from program DISTANCE for grid-based line transect distance sampling across occupied northern Idaho ground squirrel habitat in west-central Idaho, 2021.

	Estimate	Confidence Interval
Effort (km)	246.40	
# Grid cells surveyed	1,233	
# Groups detected	1,536	
Truncation distance (m)	70	
Detection probability (*p*)	0.69	0.66 – 0.72
Avg. group size (*E(S)*)	1.02	1.01 – 1.03[a]
Density (*D*)	0.67	0.59 – 0.75[a]
Population estimate (*N*)	1,963	1,736 – 2,196[a]
Adjusted index to abundance[b]	2,748	

[a] 2.5% and 97.5% quantiles of bootstrap estimate.
[b] Population estimate adjusted upwards by a factor of 1.4 based on comparison of line-transect distance-based survey to mark-recapture in 2020 (Wagner and Evans Mack 2020).

Table 2. Modeled population parameters from program DISTANCE for stratified grid-based line transect distance sampling across occupied northern Idaho ground squirrel habitat in west-central Idaho, 2021**.**

	Stratum 1	Stratum 2	Stratum 3	Pooled
Effort (km)	130.55	39.20	76.65	
# Groups detected	844	188	504	
# Grid cells surveyed	653	196	384	
Truncation distance (m)	70	70	70	
Detection probability (*p*)				0.69 (0.66 – 0.72)
Avg. group size (*E(S)*)				1.02 (1.01 – 1.02)[a]
Density (*D*)	0.70 (0.60 – 0.79)[a]	0.51 (0.36 – 0.70)[a]	0.71 (0.59 – 0.83)[a]	
% Coefficient of variation of *D*	7.10	17.49	8.84	
Population estimate (*N*)	951 (821 – 1,080)[a]	201 (141 – 275)[a]	829 (690 – 977)[a]	1,980 (1,768 – 2,200)[a]

[a] 2.5% and 97.5% quantiles of bootstrap estimate.

Population Abundance Trajectory

Based on all data and analyses, there were fewer NIDGS in 2021 compared with 2020 (Table 3). The population estimates for all survey data showed a 22% lower estimate in 2021 than in 2020 and the 95% confidence intervals for both years did not overlap. For just the core 500 cells, on average 18% fewer NIDGS groups were detected in 2021 than in 2020, with 16% more grid cells with no detections. Based on a paired comparison of the 464 core cells surveyed both years, average detections per cell were significantly lower in 2021 ($t = -2.67$, $p < 0.01$; Table 3).

Table 3. Comparison of northern Idaho ground squirrel population metrics for years 2021 and 2020 across occupied habitat in west-central Idaho.

Method and Metrics	2021	2020 [a]
All Strata[b]		
# Grid cells surveyed	1,233	1,126
# Groups detected	1,536	1,819
Avg # detections/grid cell	1.25	1.61
% Grid cells with ≥1 detection	46%	52%
Density (*D*)	0.67 (0.59 – 0.75) [c]	0.98 (0.86 – 1.09) [c]
Population estimate (*N*)	1,963 (1,736 – 2,196) [c]	2,528 (2,235 – 2,825) [c]
Core grid cells (Ranks 1-500)[d]		
# Grid cells	466	466
# Groups detected	618	746
Avg # detections/grid cell	1.33	1.60
Density (*D*)	0.79 (0.65 – 0.94) [c]	1.00 (0.82 – 1.21) [c]
Population estimate (*N*)	1,386 (1,137 – 1,651) [c]	1,748 (1,439 – 2,127) [c]
Paired sample *t*-test[e]		
# Core grid cells	464	
Avg # detections/grid cell	1.39	
t-statistic	-2.67	
p-value	$p < 0.05$	

[a] Source data: Wagner and Evans Mack 2020.
[b] Results from program DISTANCE based on each year's sample of grid cells (3 strata) selected for surveys across a common area of inference.
[c] 2.5% and 97.5% quantiles of bootstrap estimate.
[d] Results from program DISTANCE for core grid cells in strata 1 and 2 (BAS ranks 1–500) surveyed every year.
[e] Pair-wise comparison of core cells (BAS ranks 1–500) surveyed every year. (Only 464 of the core cells were surveyed in both 2020 & 2021.)

Looking back 7 years (IDFG unpublished data), NIDGS abundance in our original sampling frame (denoted by strata 1 and 2) has been on a downward trend (Figure 4). However, with the addition of stratum 3 in 2018, the overall population has plateaued at a higher level than strata 1 and 2 reflect. Stratum 3 encompasses areas where squirrels have more recently been documented, in part as a result of squirrels moving on the landscape.

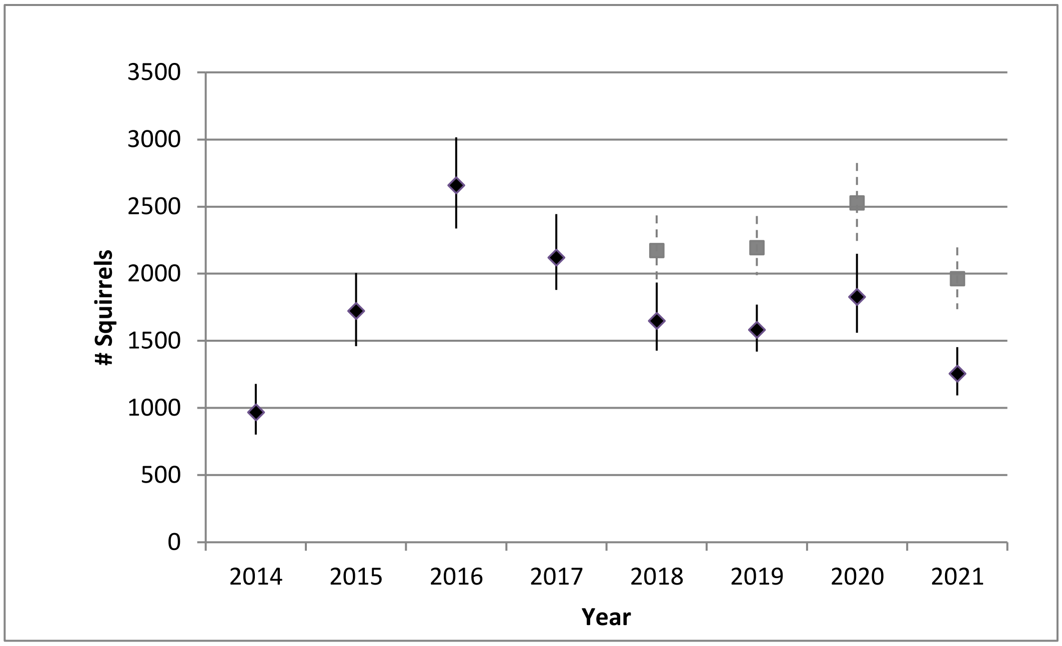

Figure 4. Unadjusted population estimates and 95% confidence intervals from program DISTANCE for strata 1 and 2 only (black); strata 1, 2, and 3 shown in gray for 2018 – 2021.

NIDGS Distribution (Occupancy)

After adjusting for detections made from grid cells that fell beyond the cell boundary, we detected NIDGS in 521 of the 1,233 cells surveyed with line-transect distance-based surveys, giving a naive occupancy of 0.42 (i.e., 42% of grid cells were occupied, without correcting for detection probability). The absolute number of sampled cells that was occupied (521) was the same as in 2020, but because we surveyed more cells in 2021, the proportion occupied declined slightly from 2020. Of the set of models examining the influence of environmental variables on occupancy with program PRESENCE, models with a constant probability of detection across visits performed better than models with a different detection probability each visit this year (Table 4). Tree canopy cover combined with soil bulk density (an indicator of soil compaction) was the most parsimonious model in predicting whether a cell was occupied based on soil, canopy, and aspect characteristics alone. The other site covariates we considered had little explanatory power (Table 4). In fact, several performed more poorly than the reference model without them.

In a second set of models, we combined the most influential environmental variables (as determined above) with NIDGS occurrence variables. The combination of tree canopy cover and the number of NIDGS detections within an immediate neighborhood (3x3 grid cell neighborhood) was the best predictor of a grid cell being occupied (Table 5). Soil bulk density was included in the most parsimonious model, but its contribution was relatively small, as the next best model without bulk density also was supported (ΔAIC<2). All of the covariates we examined that were a measure of

NIDGS occurrence around a grid cell performed better than the basic model of no covariates, illustrating the influence of “having neighbors” on whether a location would be occupied.

Table 4. Comparison of models from program PRESENCE for grid-based line-transect distance sampling incorporating only environmental covariates across occupied northern Idaho ground squirrel habitat in west-central Idaho, 2021**.**

Model	AIC	ΔAIC	AIC wt
psi(treecov, bulkden), p(.)	2907.09	0.00	0.9473
psi(treecov), p(.)	2913.61	6.52	0.0364
psi(bulkden), p(.)	2916.92	9.83	0.0069
psi(.), p(.)[a]	2918.96	11.87	0.0025
psi(silt), p(.)	2919.03	11.94	0.0024
psi(heatload), p(.)	2919.81	12.72	0.0016
psi(aspect), p(.)	2920.78	13.69	0.0010
psi(soildep), p(.)	2920.91	13.82	0.0009
psi(.), p(visit)[b]	2920.99	13.90	0.0009

[a] Reference model using constant probabilities of occupancy and detection.

[b] Reference model using constant probability of occupancy and probability of detection varying across visits.

Table 5. Comparison of models from program PRESENCE for grid-based line-transect distance sampling incorporating NIDGS occurrence and environmental covariates across occupied northern Idaho ground squirrel habitat in west-central Idaho, 2021**.**

Model	AIC	ΔAIC	AIC wt
psi(det3x3, treecov, bulkden), p(.)	2610.81	0.00	0.5427
psi(det3x3,treecov), p(.)	2611.32	0.51	0.4205
psi(det3x3), p(.)	2616.19	5.38	0.0368
psi(occ3x3), p(.)	2703.02	92.21	0.0000
psi(det5x5), p(.)	2729.25	118.44	0.0000
psi(occ5x5), p(.)	2801.31	190.50	0.0000
psi(.), p(.)[a]	2918.96	308.15	0.0000
psi(.), p(visit)[b]	2920.99	310.18	0.0000

[a] Reference model using constant probabilities of occupancy and detection.

[b] Reference model using constant probability of occupancy and probability of detection varying across visits.

Based on the reference model with no covariates [psi(.), p(.)], the probability of detection, given a cell was occupied, was estimated at 0.53 (95% CI 0.49–0.57) for each of the 3 visits. The probability of missing a squirrel on an occupied site was 0.25. Thus, we could have missed detecting presence on 25% of surveyed transects. We detected presence on at least 75% of occupied sites.

We applied the most parsimonious model (Table 5) to all 2,930 cells in our expanded sampling frame, using covariate values to predict probability of occupancy for the cells we did not survey this year. With this model, a third (33%) of cells in our expanded sampling frame had >75% probability of being occupied, a quarter had >90% probability, and 15% had <10% probability of being occupied. The number of cells with higher probability of being occupied was similar to 2020, and we had fewer grid cells in 2021 with the lowest probability (<10%) of being occupied than in 2020. We explored the extent to which stratum 3 cells contributed to occupancy, given that (1) stratum 3 cells are subjectively added to the sampling frame in part because they encompass locations where we detect squirrels, and (2) that they may in fact compensate for squirrels moving from locations in strata 1 and 2. Our naïve occupancy rates (# of grid cells detected / # surveyed) were highest in stratum 3 in 2021 (0.44 compared with 0.42 and 0.32 in strata 1 and 2, respectively). We examined whether stratum 3 had greater probability of being occupied across the entire sampling frame. Results were equivocal; stratum 3 had greater proportions of grid cells in the higher probability categories (0.5 to 0.9) and fewer cells with very low probability (<0.1) compared with the original group of grid cells established in 2014. However, the original group had a higher proportion of cells with the highest probability (> 0.9) of being occupied (Figure 5).

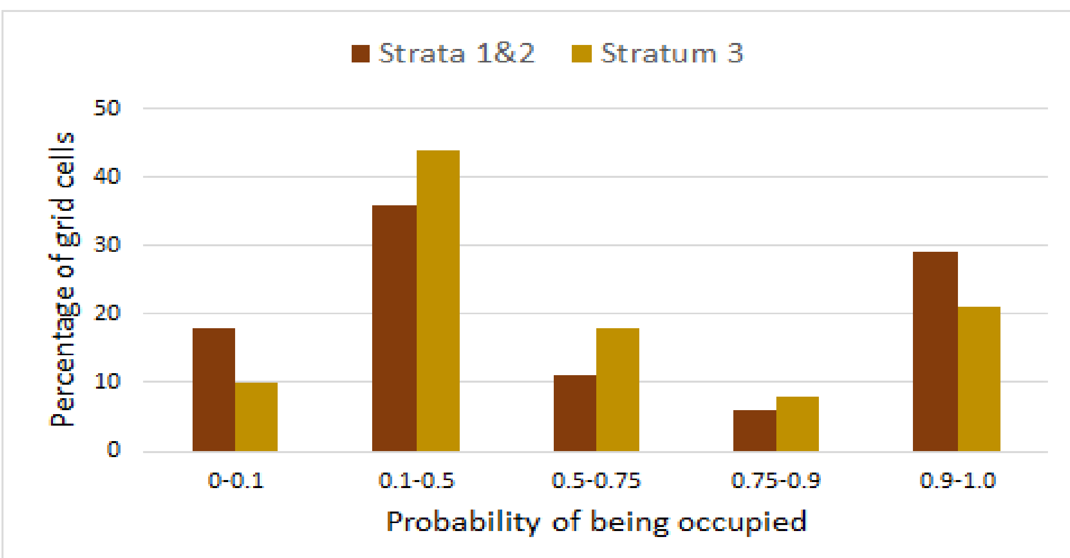

Figure 5. Stratum 3, added to the sampling frame in 2018 and revised in 2021, has fewer grid cells with the highest estimated probability of occupancy (>0.90) compared with the original sampling frame established in 2014 (strata 1 and 2), but also fewer cells in the lowest probability of occupancy category (<0.10).

Presence/Exploratory Surveys

We visited 56 additional areas (889 ha covered) in 2021 to determine presence of NIDGS. We included areas that did not contain selected grid cells in 2021; areas where we had detected NIDGS in a previous year during an exploratory survey, but they needed corroboration so were not included in the new stratum 3 layer; and completely new areas within suitable habitat. We detected 98 NIDGS at 26 of these locations, and most detections were within or adjacent to existing sites. We also had detections in new areas near Fawn Creek, Hoo Hoo Gulch, and multiple locations on the OX Ranch. Data from presence and exploratory surveys was used to determine if sites were extant, not for annual abundance or occupancy analyses.

Columbian Ground Squirrels and Badger Activity

A total of 615 Columbian ground squirrels were detected at 64 sites in 2021. This was slightly less than the number of detections made in 2020 (663) and similar to 2018 (600). Lost Valley Reservoir had the highest number of any single location (97 squirrels), but still less than in 2020 (149) or 2018 (175). We saw a noticeable increase in abundance at East Fort Lost Creek, Fawn Creek, Round Valley, Slaughter Gulch, West Pines, and several Price Valley sites compared to 2020.

We noted badger activity at 28 locations with 172 recent digs. Bear Meadow North, Lost Valley Reservoir and Rocky Comfort Flat had the most digs. The majority of the activity we recorded was fresh digs, but we did observe a badger out foraging at the Lick Creek Feedlot site. The University of Idaho's (UI) NIDGS research crew also recorded numerous and frequent fresh badger digs at study plots, clearly excavating NIDGS nest burrows. Our crew did not attempt to live-capture and relocate any badgers in 2021. USDA Wildlife Services, under contract with the U.S. Fish and Wildlife Service (USFWS) and UI, targeted 3 sites for lethal removal (Steves Creek, Fawn Creek, and Lower Butter). At least 1 badger was removed at Fawn Creek.

DISCUSSION

Based on our standardized surveys, the estimated abundance of NIDGS decreased in 2021 compared with 2020 and was the first measureable drop in estimated population size in four years (IDFG unpublished data). This occurred despite the fact that we covered more ground and visited more survey cells in 2021. Our results were mirrored by the UI research, which found that, at 7 of 10 study sites, the number of adult NIDGS live-trapped was the lowest in the last 5 years (Allison et al. 2020; C. Conway, personal communication). Late spring emergence could have been a factor, as well as a dry early summer. In terms of distribution, the proportion of cells occupied was slightly lower in 2021, although across the sampling frame the number of cells with a high probability of being occupied was similar to 2020. In summary, we detected fewer squirrels in fewer places than 2020. The periodic addition of grid cells to the sampling frame (referred to as stratum 3) improved the overall abundance estimate of the NIDGS population, demonstrating that expanding the sampling frame to encompass changing NIDGS distribution on the landscape is an important part of the monitoring design.

Site covariates, derived primarily from spatial (GIS) data, allowed us to predict the probability of occupancy for cells we did not survey based on how similar the site conditions were to those we did survey and had detections. Results of these models differ depending on the covariates selected. After 4 years of exploring relationships with a suite of environmental and NIDGS detection covariates, the combination of proximity to other squirrels and tree canopy cover consistently had the greatest influence on the likelihood of a site being occupied. Given that NIDGS are loosely colonial, it makes sense that locations near other squirrels have higher probability of being occupied. Other environmental variables we think should be important for a ground-dwelling mammal, such as soil characteristics and aspect, had limited predictive power within the suite of covariates we modeled, but in models limited strictly to environmental conditions (without squirrel occurrence) they often ranked high. Interestingly, soil depth was an influential variable in 2020 analyses, but that was replaced by soil bulk density in 2021. This could reflect the expansion of the sampling frame in 2021 in that the areas added might have had different conditions on the landscape.

Are NIDGS Extirpated at the Huckleberry Site?

Our long-term sampling design moves away from the old site-based method of tracking populations. However, there still is interest in following the status and history of specific locations on the landscape, particularly those that have supported robust numbers of NIDGS in the past but now appear to be in decline, or sites that rebound after decline. Most notable this year was the apparent extirpation of NIDGS at Huckleberry. This site was documented as early as 1938 (Howell 1938; E. Yensen, personal communication) and had been the only historical NIDGS site (from a group including Van Wyck, New Meadows, and 2 miles south of Cascade) known to still be extant. Our annual surveys document a recent gradual decline in detections, down to 1 individual in 2020 and none in 2021, and a contraction of occupied habitat. The UI study did not capture a NIDGS here in 2020 or 2021. Interestingly, this site had a similar pattern in the early 2000s, when detections dropped to <5, low enough that a rescue translocation was considered (Evans Mack 2004). A subsequent trapping effort estimated at least 20 individuals present, and the subpopulation had increased to ~30 adults by 2006. However, by 2012 numbers had declined again and the occupied footprint of the site was much reduced. Coincident with the decline was the expansion of Columbian ground squirrels throughout the site. The situation at Huckleberry demonstrates the vulnerability of isolated NIDGS sites in a changing landscape.

RECOMMENDATIONS

- Prioritize field efforts on determining the status of NIDGS at the Huckleberry site.
- Coordinate with the Payette National Forest to develop a monitoring strategy for invasive grasses.
- Continue to implement long-term monitoring as designed in 2014.
- Periodically expand stratum 3 with additional grid cells, beginning with areas where NIDGS were discovered during 2021, and recalculate the BAS ranking for stratum 3 grid cells.

- Repeat a comparison of survey to mark-recapture estimates every 3–5 years to validate survey results with mark-recapture live-trapping. Validation should be based on a minimum of 10 well-distributed and well-defined geographic areas wherein distance sampling occurs on transects completely covering the area and 3–4 trapping occasions occur within the same area. For efficiency, a validation effort should be coordinated with other ongoing studies to minimize multiple trapping sessions or surveys at sites.
- Advise the Payette National Forest to continue to conduct clearance surveys for small projects as presence/absence surveys. If NIDGS are detected, these locations will be added to the stratum 3 layer and incorporated into systematic sampling in a following year. If a target area is very large and there is a desire to estimate NIDGS density rather than presence, we recommend surveys be conducted within the grid-based framework established for long-term monitoring such that data can be compared. Specifically, surveys will tier to the range-wide 100-m x 100-m grid. If not all grid cells within the defined geographic area of interest can be surveyed, cells should be selected following the same equal-probability sampling procedure (e.g., BAS) and surveys conducted following the same standard operating procedures as the long-term monitoring design.
- Pursue long-term protection for key privately-owned sites by outright acquisition (Recovery Land Acquisition grants), conservation easements, or long-term Safe Harbor agreements. A comprehensive conservation strategy for NIDGS on private land in Round Valley, Price Valley, and the Mud/Little Mud Creek drainages should be developed.

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APPENDIX A. Description and source data for 10 environmental and occurrence covariates used in NIDGS occupancy modeling, 2021.

Covariate	Description	Data Source
southerly aspect <asppcSOUTH>	proportion (%) of a 100m circular neighborhood with a southerly aspect (SE, S, SW; 113–248 degrees)	10-meter digital elevation model (USGS 2017)[a]
soil bulk density <bulkdens30>	bulk density (g/cm3), averaged in first 1m of soil; weight of soil in a given volume	30-meter resolution POLARIS soils data (Chaney et al. 2016)[b]
heat load index <heatMEAN>	average heat load index within 100m circular neighborhood; a temperature index that ranges from 0 (coolest) to 1 (hottest) accounting for aspect and steepness of slope	derived from 10-meter digital elevation model (USGS 2017) using the Geomorphometry and Gradient Metrics v2.0 toolbox (Evans et al. 2014)[c]
silt % 30–100 cm <silt30100>	% silt in the 30–100 cm depth layer	30-meter resolution POLARIS soils data (Chaney et al. 2016)[b]
soil depth <resdep30>	depth to restrictive layer (cm)	30-meter resolution POLARIS soils data (Chaney et al. 2016)
tree canopy cover <treeMEAN>	mean tree canopy cover (%) within a 100m circular neighborhood	30-meter resolution NLCD 2016 USFS Percent Tree Canopy (Analytical Version) (USGS 2019)[d]
% occupied 3x3 <occ3x3> % occupied 5x5 <occ5x5>	proportion of grid cells occupied during 2019–2021 period within a 3x3 and a 5x5 grid cell neighborhood around each grid cell, taken in turn, based on survey and incidental detections	IDFG unpublished NIDGS occurrence data
Mean detections 3x3 <detsum3x3> Mean detections 5x5 <detsum5x5>	average, within 3x3 and 5x5 neighborhoods, of the mean # of detections per grid cell across the 2019–2021 3-yr period based on survey and incidental detections	IDFG unpublished NIDGS occurrence data

[a] USGS. 2017. 1/3rd arc-second Digital Elevation Models (DEMs) - USGS National Map 3DEP Downloadable Data Collection. Raster Digital Data Set. Available at: https://www.usgs.gov/core-science-systems/ngp/3dep

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